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Study of plasma parameters of a discharge

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Abstract : Plasma parameters *viz.* electron temperature, electron-, ion-saturation current density, electron density *etc* have been measured for the discharges of N_2, O_2 and Ar under various excitation conditions of discharge using a triple probe method It is found that electron temperature for monoatomic gas argon is much larger compared to diatomic gases oxygen and nitrogen in the same experimental conditions A reverse thing is observed for electron density The electron temperature increases whereas electron density decreases with the increase of discharge voltage (discharge current).

Keywords : Discharge plasma, plasma parameters, triple probe method

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1. Introduction

A discharge plasma consists of electrons, positive and negative ions and neutral species at low pressure, the ratio of which varies from case to case. It strongly depends upon the discharge conditions such as applied voltage, pressure and nature of the gas in the discharge, shape, size and separation of the electrodes *etc*. Several processes such as dissociation, association, ionization, recombination *etc*. are possible simultaneously in the discharge plasma. This makes a discharge a very complex system to study. If the discharge parameters are kept constant, the plasma can be considered stationary. Thus plasma parameters can be measured in this condition. These parameters are very important to understand the physical processes in a discharge.

In order to understand the interaction of laser beam with discharge plasma, we have used various kinds of probes (single probe, double probe, triple probe) reported in literature [1-6] to measure plasma parameters in presence and absence of laser.

A preliminary study of plasma in various conditions of discharge of N_2, O_2 and Ar using triple probe in absence of laser is reported here. A symmetrical triple probe method is a more direct method and do not require a voltage or frequency sweep to get V–I characteristic curve. It is basically a floating probe so that a little disturbance of plasma results. It is useful not only for stationary plasma but also in the case of rapidly changing time dependent ones or in the cases where the probe device travels through plasma such as sounding rockets or space ships. The other advantage with triple probe is that the plasma parameter can be determined instantaneously without any time consuming tedious calculations. The results of these studies are reported here.

2. Experimental method

The experimental set up used in the present study is shown in Figure 1. It consists of a glass discharge tube of 25 cm in length and 2 cm in diameter. It is fitted with two parallel cylindrical electrodes (1 cm in length and 0.5 cm in diameter) 3 cm apart. One end of the discharge tube is connected with a rotary pump to create low pressure in the discharge tube. The other end of the tube is connected to the cylinder to introduce the gas to be studied. A pirani gauge is also attached to this to measure the pressure in the tube. The triple probes are three tungsten wire 0.5 mm in diameter and 2 cm in length located centrally in the tube at a separation of 2 mm.

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The tube was first degassed (up to 10^{-2} mm) and then filled with the desired gas (Ar, O_2 or N_2) to an appropriate pressure (0.4 mm). A suitable D.C. voltage (600–650 volts)

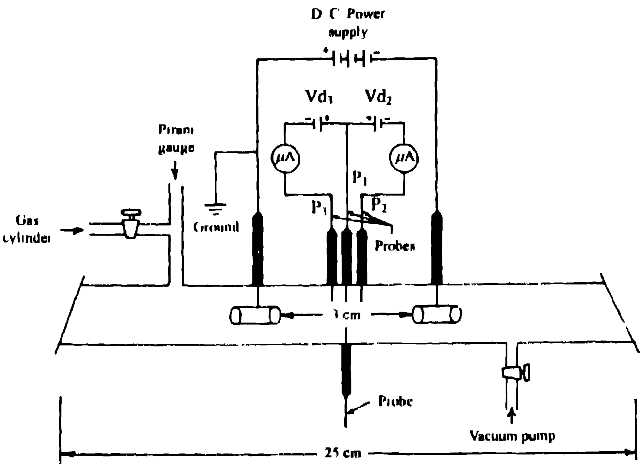

Figure 1. Experimental set-up used for the study of discharge plasma using triple probe method

was applied to the electrodes to get a suitable discharge. Once a stable plasma condition was achieved, the triple probes were biased with two low voltage stable DC power supplies V_{d2} and V_{d3} with central probe common as shown in Figure 1. The voltage of one power supply V_{d2} was kept constant for one set of measurements while that of the other V_{d3} was varied. The currents in the two circuits *viz.* I_2 and I_3 were noted with micro ammeter for different values of V_{d3}.

Table 1. Electron temperature, electron density, ions saturation current density and electrons saturation currrent density of Ar at different discharge voltage

S No	Discharge voltage	Pressure		Voltage V_{d2} = 7 volt V_{d3} in volt 7 5	10	15	20	25
1	600 volt	0.4 mm	Temp ($\times 10^{-4}$)°K	8 1	5.1	2 6	2 5	2 3
	current (3 mA)		η_e($\times 10^{-11}$) cm^{-3}	52.0	6 5	4 1	3 0	1 5
			J_i($\times 10^2$) amp^{-3}	21.2	2 12	0 95	0.64	0 32
			J_e($\times 10^4$) amp^{-3}	37.8	3.7	1 7	0 78	0.48
2	620 volt	0 4 mm	Temp ($\times 10^{-4}$)°K	9 2	6 2	3 2	2 7	2 4
	current (5 2 mA)		η_e($\times 10^{11}$) cm^{3}	19 5	8 2	3 6	2 5	1.4
			J_i($\times 10^2$) amp^{-3}	8.5	2 9	0 93	0 65	0 31
			J_e($\times 10^4$) amp^{-3}	15 1	5 1	1 7	1 0	0 46
3	650 volt	0 4 mm	Temp ($\times 10^{-4}$)°K	11 6	7.2	4 2	3 1	2.5
	current (8 mA)		η_e($\times 10^{11}$) cm^{3}	13 0	9 9	2 5	1 9	1 3
			J_i($\times 10^2$) amp^{-3}	6 3	3 8	0 74	0 49	0.29
			J_e($\times 10^4$) amp^{-3}	11 3	6 8	1.3	0 87	0 52
4	100 volt	4-31 mm	Temp. ($\times 10^{-4}$)°K		1.0 – 2.5			[7]
	current (2–8 A)		η_e($\times 10^{-13}$) cm^{-3}		10 – 100			
5	60–300 volts	10 mm	Temp ($\times 10^{-4}$)°K		2.0			[8]
	current (4 0 A)							

Several sets of measurements were taken by selecting different values of V_{d2} and correspondingly varying V_{d3}. These measurements correspond to a particular value of discharge voltage and pressure. Measurements were also made by varying the discharge voltage keeping discharge pressure the same and the current I_2 and I_3 for different values of V_{d2} and V_{d3} were noted down. These values for the argon are given in Table 1. Similar measurements were made for oxygen and nitrogen also and the corresponding values are given in Tables 2 and 3 respectively.

Table 2. Electron temperature, electron density, ions saturation current density and electrons saturation currrent density of O_2 at different discharge voltage.

S No	Discharge voltage	Pressure		Voltage V_{d2} = 7 volt V_{d3} in volt 7 5	10	15	20	25
1.	600 volts	0 4 mm	Temp ($\times 10^{-4}$)°K	2 0	0.60	0.31	0 26	0.17
	current (3 mA)		η_e($\times 10^{11}$) cm^{-3}	47 2	18 2	11 4	3 7	2 10
			J_i($\times 10^2$) amp^{-3}	95 5	20 2	9 14	2 72	1 21
			J_e($\times 10^4$) amp^{-3}	169 9	35 9	16 2	4 80	2 15
2	620 volts	0 4 mm	Temp ($\times 10^{-4}$)°K	2 5	0 65	0 35	0 28	0 19
	current (5 2 mA)		η_e($\times 10^{-11}$) cm^{-3}	37 5	16 1	9 20	3 4	1 90
			J_i($\times 10^2$) amp^{-3}	84 9	18 6	7 83	2 57	1 18
			J_e($\times 10^4$) amp^{-3}	151 1	33 0	13 9	4 5	2 11
	650 volts	0 4 mm	Temp ($\times 10^{-4}$)°K	3 0	0 75	0 40	0 30	0 20
	current (8 mA)		η_e($\times 10^{-11}$) cm^{-3}	30.2	13 0	8 3	2 3	1 30
			J_i($\times 10^2$) amp^{-3}	74 9	16 1	7 56	1 84	0.88
			J_e($\times 10^4$) amp^{-3}	133.2	28 7	13 4	3 2	1 50
	250 volts	0 1 mm						[9]
	R. F power		η_e($\times 10^{-9}$) cm		1 0			

Table 3. Electron temperature, electron density, ions saturation current density and electrons saturation currrent density of N_2 at different discharge voltage.

S No	Discharge voltage	Pressure		Voltage V_{d2} = 7 volt V_{d3} in volts 7 5	10	15	20	25
1	600 volt	0 4 mm	Temp ($\times 10^{-4}$)°K	4.0	1.8	0.32	0 25	0 15
	current (3 mA)		η_e($\times 10^{11}$) cm^{-3}	25 1	5 5	7.8	1 4	0 77
			J_i($\times 10^2$) amp^{3}	116 5	16 7	10 3	1 7	0 69
			J_e($\times 10^4$) amp^{-3}	128 1	18.3	11 3	1 9	0 7
2.	620 volt	0.4 mm	Temp. ($\times 10^{-4}$)°K	5 0	2 3	0 38	0.28	0 18
	current (5.2 mA)		η_e($\times 10^{-11}$) cm^{-3}	9 8	4.2	6 1	1.2	0 67
			J_i($\times 10^2$) amp^{-3}	50.9	15.0	8.8	1 4	0 68
			J_e($\times 10^4$) amp^{-3}	55 9	16 5	9 6	1 5	0 73
3	650 volt	0.4 mm	Temp. ($\times 10^{-4}$)°K	5.8	2.9	0 41	0.31	0 20
	current (8 mA)		η_e($\times 10^{-11}$) cm^{-3}	7 3	4.4	2 4	1.0	0.59
			J_i($\times 10^2$) amp^{-3}	41.2	17 4	6 7	1.3	0 61
			J_e($\times 10^4$) amp^{-3}	45.2	19.1	7 3	1.4	0.68

3. Results and discussion

If I_1, I_2 and I_3 are the currents flowing in the probe P_1, P_2 and P_3 respectively, then according to Chen and Sekiguchi [1]

$$I_1 = I_2 + I_3. \quad (1)$$

Now assuming that

(i) The electron energy distribution in the plasma is Maxwellian.

(ii) The thickness of the ion sheath formed in the discharge near probe electrode is smaller than the probe separation and

(iii) The mean free path of the electrons is much larger than the thickness of the ion sheath around each probe and the probe radius.

In general, in equlibrium situation, the current heating the probe is

$$I_\alpha = S q_\alpha J_\alpha e^{(-\phi v)}, \quad (2)$$

where α is the species of the particle (electrons/ions), q_α is charge of the particle of species α, j_α is current dinsity of the species α, V is the potential at probe for biasing and S is the surface area of the probe. In the case of electrons

$$J_e = \eta_e e(kT_e / 2\pi m_e)^{1/2}, \quad (3)$$

where $q_\alpha = -e$ and

$$\phi = \frac{\;}{kT_e} \quad (4)$$

J_e is the electron saturation current density, η_e is the electron density, k is the Boltzmann constant and e and m_e are charge and mass of the electron respectively. Since the cross sectional area of the three probes are the same, $S_1 = S_2 = S_3 = S$; as a special case, it may be assumed that $SJ_i(V_1) \sim SJ_i(V_2) \sim SJ_i(V_3) \equiv SJ_i(V)$. In this case, we can derive

$$\frac{(I_1+I_2)}{(I_1+I_3)}\left[\frac{1-e^{-\Phi(V_1-V_2)}}{1-e^{-\Phi(V_3-V_1)}}\right] \sim \left[\frac{1-e^{-\Phi V_d}}{1-e^{-\Phi V_d}}\right] \quad (5)$$

where I_1, I_2 and I_3 are the currents in the first, second and third probes and V_{d2} and V_{d3} are battery potential between 1, 2 and 1, 3 electrodes. From this equation, the values of Φ and thereby the electron temperature T_e can be determined provided I_1, I_2, I_3, V_{d2} and V_{d3} are known. The values of electron temperature thus obtained in different conditions for the three gasses are given in Tables (1–3). One can also derive the ion saturation current density using the relation

$$J_i = \frac{1}{S}\left[\frac{I_1 - I_2 e^{-\Phi(V_{d3}-V_{d2})}}{1-e^{-\Phi(V_{d3}-V_{d2})}}\right] \quad (6)$$

In this expression since all the terms are known, therefore ion saturation current density could be determined.

The value of electron density can not be determined directly using triple probe method. However, it can be calculated from T_e and J_i since the ion saturation current density is related to the electron density as

$$J_i = \exp(-1/2) e\eta_e \left(\frac{kT_e}{m_i}\right)^{1/2}, \quad (7)$$

where m_i is the ion mass. The electron density thus obtained for the three gases are tabulated in Tables 1, 2 and 3 respectively. From the table, it is clear that the electron temperature for the monoatomic gas argon is much larger compared to diatomic O_2 and N_2. A reverse thing is observed for electron density. Variation of electron temperature with V_{d3} for a constant value of V_{d2} (= 7 V) and discharge pressure (= 0.4 mm) for the three gases at three different voltages are shown in Figures 2a, 3a and 4a. Similarly, Figures 2b, 3b and 4b represent the variation of electron density with V_{d3}.

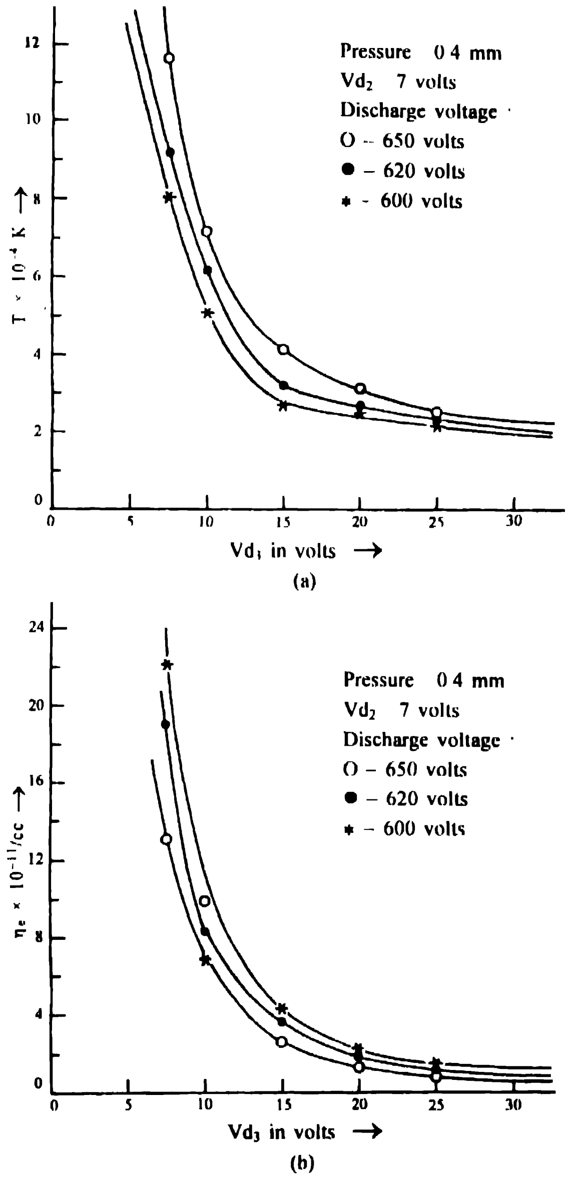

Figure 2. (a) Variation of electron temperature with V_{d3} in Ar discharge at different discharge voltages and (b) Variation of electron density with V_{d3} in Ar discharge at different discharge voltages.

From the figures one can see that for lower value of V_{d3}, the electron temperatures are higher for all the three gases. The

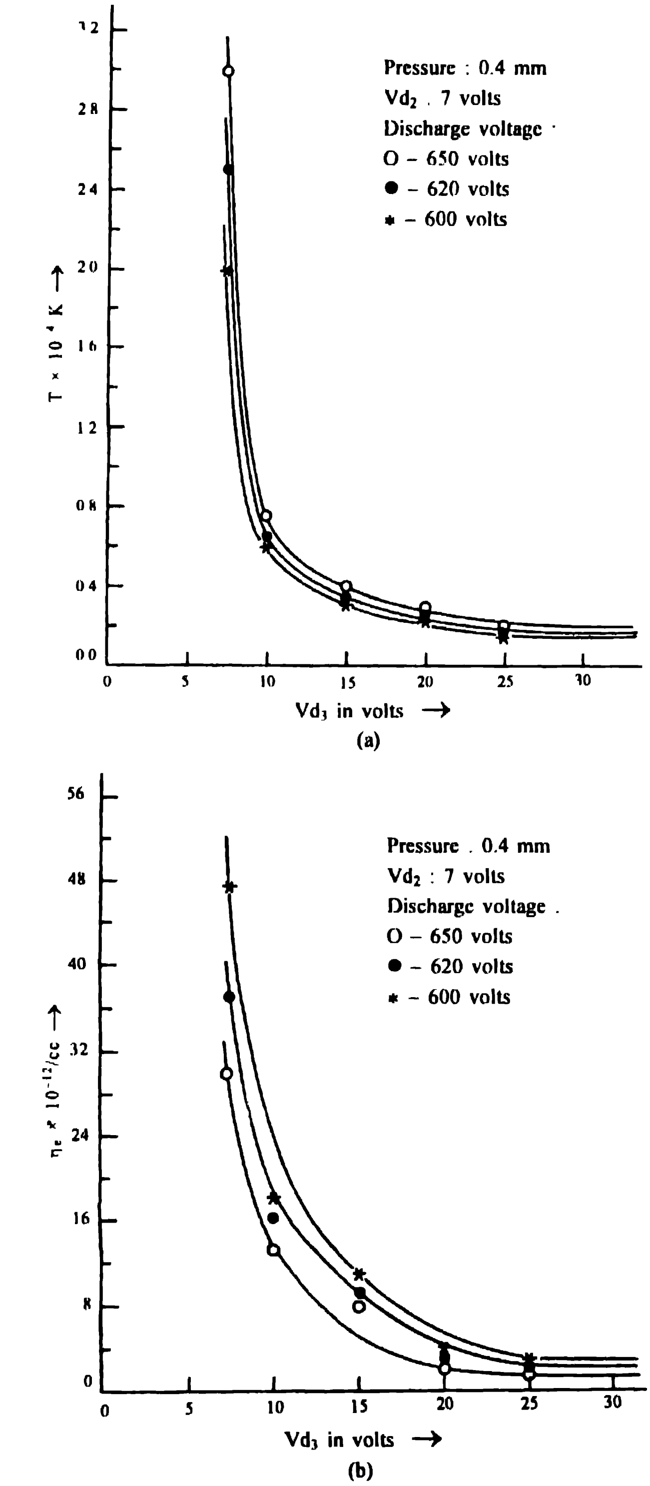

Figure 3. (a) Variation of electron temperature with V_{d3} in N_2 discharge at different discharge voltages and (b) Variation of electron density with V_{d3} in N_2 discharge at different discharge voltages

electron temperature decreases with the increase of V_{d3} and shows a saturation for higher values of V_{d3}. A similar behaviour is marked for different discharge voltages.

It is interesting to note that the electron temperature increases with the increase of discharge voltage

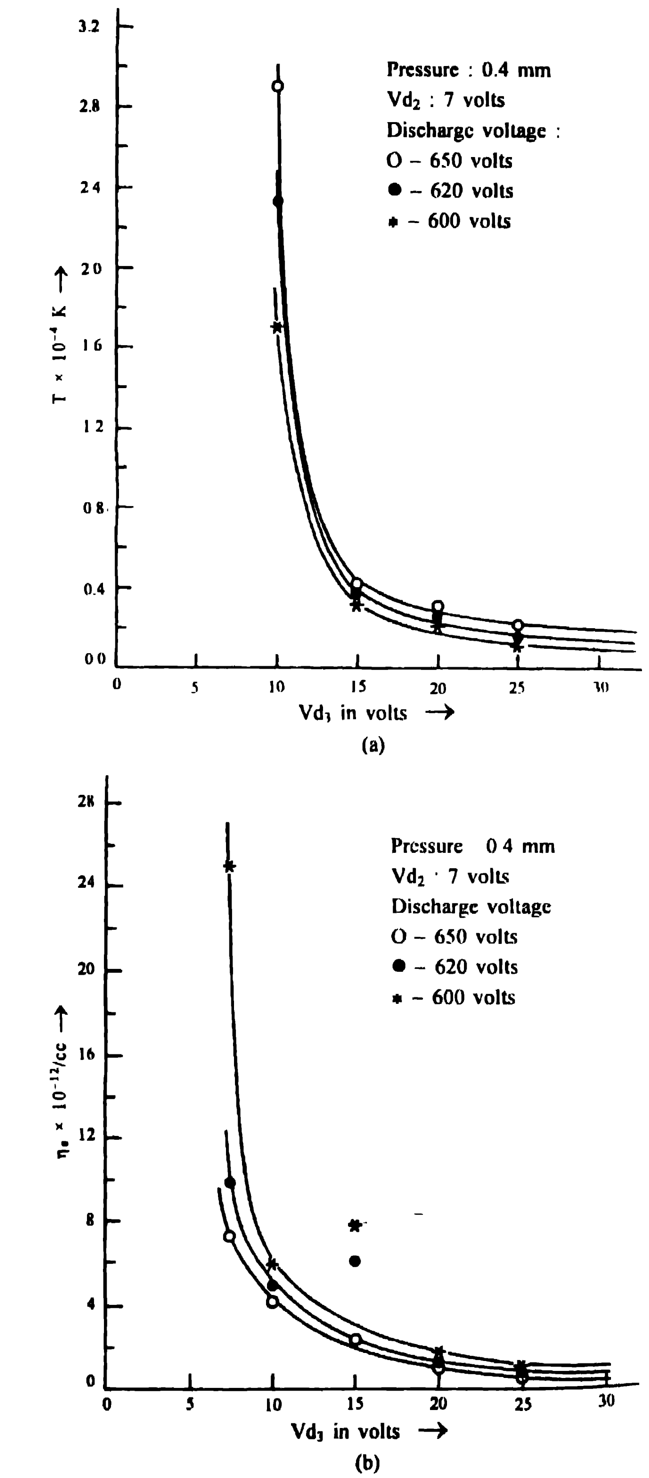

Figure 4. (a) Variation of electron temperature with V_{d3} in O_2 discharge at different discharge voltages and (b) Variation of electron density with V_{d3} in O_2 discharge at different discharge voltages.

(current); however, the electron density decreases with discharge voltage (current). The variation of electron temperature and density with discharge voltage for a fixed value of discharge pressure, V_{d2} and V_{d3} is shown in Figure 5.

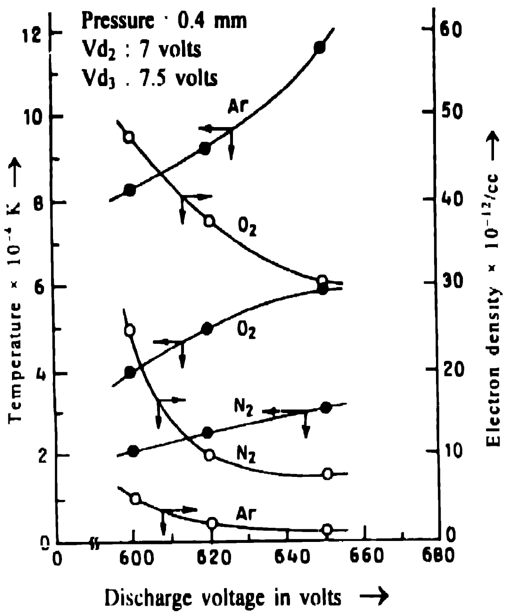

Figure 5. Variation of electron temperature and electron density with discharge voltage

We have also compared our results for Te and η_e for argon and oxygen with the earlier measurements reported in literature [7–9]. Our values are slightly different from these reported values due to different experimental conditions of our discharge.

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